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Evaluation of cotton cultivars for resistance to pathotypes of *Verticillium dahliae*

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ABSTRACT

After the recent detection of serious losses caused by Verticillium wilt of cotton, incited by the defoliating pathotype of *Verticillium dahliae* in the Aegean Region of Turkey, 28 of the most commonly grown cotton cultivars (*Gossypium hirsutum* L.) of Turkey, were evaluated for the presence of field resistance to wilt. Six-week-old plants were inoculated with a cotton nondefoliating (ND) or a cotton defoliating (D) pathotype of *V. dahliae* under controlled conditions. Resistance was evaluated on the basis of external symptoms by calculating areas under disease progress curves. The percentage of plants killed and of those which recovered from the disease was used as additional parameters for including a particular cultivar into a defined category. Most of the evaluated cultivars were susceptible, although at different levels, to both pathotypes of *V. dahliae*. All cultivars were more susceptible to the D than to the ND pathotype. The most promising cultivars in the experiments appeared to be Carmen and ST-373. Carmen showed differential resistance: it was susceptible to the D but resistant to the ND pathotype. ST-373 was moderately susceptible to both pathotypes of *V. dahliae*. A resistance related phenotypic reaction to the disease was quantified by using six growth parameters (plant height, number of nodes, leaf weight, stem weight, leaf to stem ratio, and total shoot weight) measured 13 d after inoculation. The percentage decrease in leaf–stem ratio and leaf weight were found to be the best indicators of resistance. Results obtained in this study will be useful to quantify resistance to *V. dahliae* and identify the best parameters to phenotype in genetic studies.

1. Introduction

In Turkey, about 547,000 ha of upland cotton (*Gossypium hirsutum* L.) are grown annually under irrigation in three main regions. These include the Aegean, Mediterranean and South-eastern Anatolia. In the 1990s, approximately 740,000 ha of cotton were grown in Turkey. Thereafter, a steady reduction in cotton production has occurred, because of the abandonment of dry land cotton, increased production costs, and losses due to pests and diseases (Özüdoğru, 2006).

Verticillium wilt, incited by the soil inhabiting fungus *Verticillium dahliae* Kleb. is among the most serious diseases of cotton throughout Turkey causing substantial economic losses. It was first reported in Turkey in 1941 (İyriboz, 1941), but was not identified as an important disease under field conditions until 1967 (Karaca et al., 1971). Since 2000, severe Verticillium wilt has progressively increased in many fields, and an unusually high incidence of a severe wilt disease of cotton has been observed in the Aegean region. This high level of disease has been attributed to new races of *V. dahliae*, or to potassium deficiency, or to the change in tolerance to Verticillium wilt in cv. Nazilli 84 (Göre et al., 2007). Results of the pathogenicity and vegetative compatibility tests, performed by Göre (2007), indicate clearly that increased losses caused by severe wilt in cotton fields in the Aegean region are due to the presence of a highly virulent, D pathotype of *V. dahliae* belonging to vegetative compatibility group one (VCG1).

Severity of attacks by *V. dahliae* depends upon virulence (i.e., the amount of disease caused in a host genotype) of the pathogen isolates (Bell, 1994). *V. dahliae* isolates infecting cotton can be classified into D and ND pathotypes, based on their ability to cause defoliation or not of leaves from shoots (Bejarano-Alcázar et al., 1995, 1996). The ND pathotype is moderately severe and D one is highly virulent on cotton (Schnathorst and Mathre, 1966; Schnathorst et al., 1975). In Turkey, both pathotypes of *V. dahliae* were found infecting cotton (Göre, 2007; Göre et al., 2007). They are present in cotton areas planted with the Turkish cultivars BA-119, BA-Gold, M-503, Nazilli 84-S, ST-373, ST-468, ST-488 and Şahin 2000. The spread of D pathotype in Turkey (Göre et al., 2007) and its

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presence in commercial cotton fields (Göre, 2007; Göre et al., 2007) make it necessary to determine the susceptibility of cotton cultivars to *V. dahliae*.

Control of *V. dahliae* is difficult under intensive cropping systems, such as those adopted in the area infested with the disease in Turkey. Currently, no fungicides are registered for control of this disease on cotton. In addition, the ability of sclerotia of the fungus to survive in the soil for seven or more years (Wilhelm, 1955) and the wide host range of the fungus, make cultural control difficult, emphasizing the need for resistant cultivars (Heale, 1988). The level of resistance in commercial cultivars is unknown and potential sources of resistance to the pathogen in cotton have not been studied to date in Turkey, with the exception of the work by Mert et al. (2005).

The purpose of the first large screening study was to determine the level of resistance to the both pathotypes of *V. dahliae* in commercial cotton cultivars under growth chamber conditions in order to provide useful information to local growers as well as to breeders, who could use this information to develop new lines or germplasm resistant to Verticillium wilt and to determine the best plant parameters to indicate resistance.

2. Materials and methods

Twenty-eight of the most commonly grown cotton cultivars were evaluated for resistance to *V. dahliae* in controlled conditions. The cultivars; Aksel, BA-119, BA-151, BA-308, BA-525, BA-Gold, Flaş, Şahin 2000 and Tex were kindly supplied by Özbuğday Seed Research Company (Antakya, Turkey), Candia, Carmen, Celia, Flora and Julia by Bayer Crop Science AG (Leverkusen, Germany), Sayar 314 by Çukurova Agricultural Research Institute (ÇARI) (Adana, Turkey), DD-493, Delta Opal, DP-388, DP-419 and SG-125 by Monsanto (St. Louis, MO, USA), Erşan 92 and Maraş 92 by Kahramanmaraş Agricultural Research Institute (KARI) (Kahramanmaraş, Turkey), M-503 and Nazilli 84-S by Nazilli Cotton Research Institute (NCRI) (Aydın, Turkey), ST-373, ST-453, ST-468 and ST-488 by May Çukonar Seed Corporation (Bursa, Turkey). These cultivars comprised approximately 98% of cotton plantings in Turkey in 2007. Plants were inoculated with isolates of *V. dahliae*, I/22 (VCG2B) and Mn/8 (VCG1), from the collection of the Plant Pathology Laboratory of Plant Protection Research Institute, Izmir, Turkey. Isolate I/22 represents a highly virulent, cotton ND pathotype, and Mn/8 a highly virulent, cotton D pathotype (Göre, 2007). Both isolates maintain the same differential pathogenicity in cotton. Two cotton cultivars, Deltapine 15-21 and Çukurova 1518, were included in each experiment because both of these cultivars are susceptible to both the D and ND pathotypes (Mert et al., 2005; Schnathorst and Mathre, 1966).

Plants were inoculated by the stem-injection method (Bejarano-Alcázar et al., 1996). For stem-injection inoculation, disinfested (1% NaOCl for 2.5 min) germinated seeds were sown in 15-cm-diameter pots (one plant per pot) filled with a sterilized potting mixture (sand:clay loam:peat; 1:1:1, vol:vol). The cotton cultivars were randomly divided into two equal groups. Each group was grown in a growth chamber under fluorescent illumination of 216–270 $\mu E\ m^{-2}\ s^{-1}$, 14:10 L:D. Temperature and relative humidity, were 24–27 °C and 50–70% respectively, during the light period, and 18–22 °C and 60–80% during the dark period. Plants were watered as required and fertilized every 2 weeks with a water soluble fertilizer (20-10-20, N:P:K). Six-week-old plants were inoculated with 6 μl of a 4×10^6 conidia ml^{-1} suspension in sterile distilled water (Bugbee and Presley, 1967). Control plants were treated similarly with sterile distilled water. To evaluate wilt resistance, disease severities were assessed daily for 13 d, starting 7 d after inoculation. A scale 0–4 was used according to the percentage of foliage affected by chlorotic, necrotic and wilt symptoms and/or defoliation, in an acropetal progression (0 = no symptoms; 1 = 1–33% foliage affected; 2 = 34–66% foliage affected; 3 = 67–100% foliage affected; 4 = dead plants). The percentage of dead plants (PDP), recovery from the disease and other symptoms such as marginal spots of leaves and irregular growth of terminal buds were also considered to estimate the severity of reactions. The area under the disease progress curve (AUDPC) was calculated for each treatment from the assessment of disease incidence using the formula:

$$\mathrm{AUDPC} = \sum_{i=1}^{n-1}\left(\frac{y_i + y_{i+1}}{2}\right)(t_{i+1} - t_i)$$

where y_i is the disease incidence in percent at ith assessment, t_i is the time of the ith assessment in days from the first assessment date, and n is the total number of days the disease was assessed (Campbell and Madden, 1990).

The relationship between disease severity and growth was investigated by measuring several growth parameters 2 weeks after inoculation. Plant height was measured from the cotyledonary node to the top of the plant. The number of nodes per plant was counted from the cotyledonary node to the top of the plant. Leaves taken from both the main stem and secondary branches with their petioles attached were used to determine leaf weight. Stem weight was measured by weighing the stem that was cut at the cotyledon node and stripped of leaves and fruits. After these measurements, leaf–stem ratio and shoot weight were calculated from leaf weight and stem weight (Bölek et al., 2005).

Plant infection was verified by the isolation of the fungus from affected shoots during the experiments. Isolations were taken from three randomly selected plants for each cultivar/pathotype combinations. Pieces of affected tissues were washed in running tap water, bark was removed and woody tissues surface disinfected in 0.5% sodium hypochlorite for 1 min. Chips of wood were placed onto PDA. Plates were incubated at 24 °C in the dark and for 5–6 d.

In both experiments, plants were arranged according to a split-plot completely randomized block design with ten replicated plants per cultivar/pathotype combination. The main plot was the *V. dahliae* pathotypes, and cultivars were assigned to sub-plots. Data collected for the six previously mentioned traits to indicate resistance or susceptibility from disease screening were subjected to analysis of variance in order to calculate F-values and correlation coefficients (SAS Institute, 2000). LSD was calculated to separate mean values.

3. Results

Symptoms ranging from sudden wilt or apoplexy, to severe chlorosis of leaves and stunting, were observed in plants inoculated with the D or the ND *V. dahliae* pathotype. Chlorosis was the most common symptom observed within 10 d after inoculation when the ND pathotype was used. Leaves became necrotic but remained attached to the stems. In plants inoculated with the D pathotype, chlorosis was associated with cultivars showing certain level of resistance and defoliation was also common. It occurred, in the absence of chlorosis, in most of the susceptible cultivars inoculated with the D pathotype, starting at 7 d, and intensifying from the tenth day, after inoculation. Defoliation ranged from intensive in susceptible cultivars such as BA-151, Celia, Flaş, Maraş 92 and SG-125, to slight and restricted to the middle of the main shoots in moderately susceptible cultivars such as BA-119, ST-373 and Tex. The D pathotype induced a higher incidence of disease and symptom severity than the ND and earlier death of plants. The D

Table 1
DSI, AUDPC, PDP and susceptibility of cotton cultivars inoculated with D and ND pathotypes of *Verticillium dahliae*.[a]

Cultivar	Company	Mean DS[b] assessed daily after inoculation							AUDPC[b]	PDP[b]	S[b,c,d]
		7	8	9	10	11	12	13			
Defoliating											
Aksel	Özbuğday	13.75	27.50	43.13	65.63	75.00	78.13	85.63	339.06	43	S
BA-119	Özbuğday	0.00	2.50	18.13	31.88	64.38	72.50	75.00	226.88	0	MS
BA-151	Özbuğday	0.00	24.38	46.88	65.63	83.13	89.38	90.63	354.69	63	E
BA-308	Özbuğday	0.00	10.63	28.13	50.00	68.13	75.00	78.75	271.25	15	S
BA-525	Özbuğday	0.00	10.63	32.50	53.75	75.00	75.00	76.88	285.31	8	S
BA-Gold	Özbuğday	11.25	21.88	53.13	56.25	75.00	84.38	84.38	338.44	38	S
Candia	Bayer	3.13	13.75	35.63	46.25	63.75	68.13	75.00	266.56	0	S
Carmen	Bayer	18.75	30.00	47.50	60.63	75.00	77.50	78.13	339.06	13	S
Celia	Bayer	0.00	21.25	31.88	46.25	75.00	75.00	93.13	295.94	73	S
Çukurova 1518	ÇARI	56.25	69.38	69.38	87.50	88.13	94.38	98.13	485.94	93	E
DD-493	Monsanto	18.13	35.63	56.88	64.38	75.00	75.00	81.88	356.88	28	E
Delta Opal	Monsanto	6.88	25.00	35.63	53.13	68.13	75.00	75.00	297.81	0	S
DP 15-21	ÇARI	25.00	35.00	57.50	60.00	65.00	70.00	75.00	337.50	0	S
DP-388	Monsanto	0.00	6.88	28.13	50.00	75.00	75.00	78.75	274.38	15	S
DP-419	Monsanto	25.00	28.13	39.38	50.00	71.88	75.00	75.00	314.38	0	S
Erşan 92	KARI	10.00	25.00	46.88	60.00	60.00	60.00	60.00	286.88	0	S
Flaş	Özbuğday	0.00	3.13	18.13	43.13	75.00	78.13	86.25	260.63	45	S
Flora	Bayer	0.00	25.00	28.13	46.25	75.00	75.00	75.00	286.88	0	S
Julia	Bayer	3.13	28.13	39.38	50.00	75.00	75.00	76.25	307.19	5	S
M-503	NCRI	17.50	22.50	52.50	67.50	75.00	77.50	78.13	342.81	13	S
Maraş 92	KARI	30.00	36.25	67.50	67.50	77.50	82.50	86.88	389.69	48	E
Nazilli 84-S	NCRI	27.50	44.38	66.88	71.88	78.13	88.75	80.63	404.06	23	E
Sayar 314	ÇARI	0.00	10.63	46.88	55.63	58.13	69.38	78.13	279.69	13	S
SG-125	Monsanto	10.63	25.00	53.13	64.38	78.13	89.38	96.25	363.44	85	E
ST-373	May Çukonar	0.00	10.63	21.25	39.38	56.88	60.63	68.13	222.81	0	MS
ST-453	May Çukonar	21.25	20.00	45.00	57.50	72.50	80.00	80.00	325.63	20	S
ST-468	May Çukonar	3.13	21.25	46.25	68.13	75.00	75.00	75.00	324.69	0	S
ST-488	May Çukonar	6.88	21.25	53.13	68.13	75.00	75.00	84.38	338.13	38	S
Şahin 2000	Özbuğday	0.00	10.63	44.38	55.63	71.88	71.88	71.88	290.31	0	S
Tex	Özbuğday	0.00	12.50	37.50	42.50	60.00	65.00	65.00	250.00	0	MS
Nondefoliating											
Aksel	Özbuğday	2.50	27.50	42.50	57.50	75.00	77.50	83.13	322.81	33	S
BA-119	Özbuğday	0.00	10.00	22.50	47.50	72.50	75.00	75.00	265.00	0	S
BA-151	Özbuğday	7.50	25.00	35.00	60.00	75.00	75.00	77.50	312.50	10	S
BA-308	Özbuğday	0.00	14.38	25.00	43.13	68.13	75.00	75.00	263.13	0	S
BA-525	Özbuğday	0.00	14.38	39.38	56.88	71.25	71.25	72.50	289.38	0	S
BA-Gold	Özbuğday	16.25	27.50	55.00	60.00	72.50	75.00	76.88	336.56	8	S
Candia	Bayer	3.13	18.13	31.88	42.50	67.50	75.00	75.00	274.06	0	S
Carmen	Bayer	5.00	17.50	20.00	20.00	40.00	50.00	50.00	175.00	0	R
Celia	Bayer	0.00	10.63	28.13	39.38	75.00	75.00	78.75	267.50	15	S
Çukurova 1518	ÇARI	43.75	60.63	64.38	67.50	78.13	85.00	91.88	423.44	68	S
DD- 493	Monsanto	6.88	25.00	46.25	53.75	71.25	75.00	75.00	312.19	0	S
Delta Opal	Monsanto	6.88	21.88	28.13	46.25	71.88	75.00	75.00	284.06	0	S
DP 15-21	ÇARI	31.25	46.25	56.25	59.38	59.38	65.63	70.00	337.50	0	S
DP-388	Monsanto	3.13	21.88	35.63	56.88	75.00	75.00	75.00	303.44	0	S
DP-419	Monsanto	10.63	25.00	42.50	60.63	71.25	75.00	75.00	317.19	0	S
Erşan 92	KARI	0.00	17.50	27.50	40.00	57.50	62.50	62.50	236.25	0	MS
Flaş	Özbuğday	0.00	0.00	10.63	21.25	56.88	75.00	75.00	201.25	0	MS
Flora	Bayer	0.00	14.38	21.25	31.88	71.25	71.25	71.25	245.63	0	MS
Julia	Bayer	28.13	35.63	53.13	68.13	75.00	75.00	75.00	358.44	0	E
M-503	NCRI	11.25	32.50	57.50	57.50	67.50	67.50	70.00	323.13	0	S
Maraş 92	KARI	27.50	37.50	53.13	62.50	62.50	75.00	78.75	343.75	15	S
Nazilli 84-S	NCRI	37.50	52.50	57.50	57.50	65.00	65.00	65.00	348.75	0	S
Sayar 314	ÇARI	37.50	45.00	67.50	67.50	70.00	75.00	76.25	381.88	5	E
SG-125	Monsanto	0.00	3.13	10.63	25.00	68.13	71.25	71.25	213.75	0	MS
ST-373	May Çukonar	0.00	10.63	31.88	50.00	60.63	64.38	67.50	251.25	0	MS
ST-453	May Çukonar	21.88	31.25	53.13	60.63	69.38	71.88	71.88	333.13	0	S
ST-468	May Çukonar	6.88	28.13	46.88	60.63	75.00	75.00	75.00	326.56	0	S
ST-488	May Çukonar	10.63	28.13	46.25	71.88	75.00	75.00	75.00	339.06	0	S
Şahin 2000	Özbuğday	2.50	12.50	25.00	42.50	55.00	67.50	67.50	237.50	0	MS
Tex	Özbuğday	15.00	37.50	37.50	55.00	57.50	57.50	57.50	281.25	0	S

[a] Six-week-old cotton plants were inoculated with cotton-ND or cotton-D pathotype of *V. dahliae*. Symptom severity was assessed daily from 7 to 13 days after inoculation.
[b] DS = disease severity (%); AUDPC = area under the disease progress curve; PDP = percentage of dead plants; S = susceptibility.
[c] R = resistant; MS = Moderately susceptible; S = susceptible; E = extremely susceptible. Susceptibility has been determined according to values of AUDPC, PDP at 13 days after inoculation.
[d] Resistance categories correspond to following interval of values of AUDPC for the D/ND pathotypes of *V. dahliae*: HR = 0-65; R = 66-190; MS = 191-255; S = 256-350; E = 351–510.

pathotype caused between 5% and 100% mortality in 19 out of the 30 cultivars inoculated, whereas mortality was only observed in seven of them when the ND pathotype was used (Table 1). From the thirteenth day after inoculation, only one cultivar, Nazilli 84 S, showed recovery from the disease, expressed as a reduction in disease severity and was associated with a certain level of resistance. This phenomenon was not observed in cultivars inoculated with the ND pathotype (Table 1).

Table 2
Analysis of variance of thirty cotton cultivars for traits associated with resistance to Verticillium wilt.[a]

Source of variation	d.f.	Mean sum of square						
		Plant height (cm)	Number of nodes	Leaf weight (g)	Stem weight (g)	Leaf–stem ratio	Shoot weight (g)	Verticillium wilt index
Replication	9	7.64	0.84	4.86	0.38	0.74	6.17	0.06
Cultivar	29	94.49[b]	7.99[b]	29.13[b]	7.08[b]	3.83[b]	54.00[b]	1.65[b]
Pathotype	1	195.24[b]	32.41[b]	167.98[b]	12.85[b]	36.81[b]	273.78[b]	10.59[b]
Cultivar × Pathotype	29	22.79[b]	1.56[b]	6.63[b]	0.95[b]	2.22[b]	9.12[b]	0.40[b]
Error	522	5.50	0.46	2.39	0.28	0.53	3.21	0.13

[a] Statistical analysis by least significance difference (LSD) test.
[b] Significant at 0.01%.

Cultivars were classified into resistance categories as shown in Table 1. Most of the cultivars were more susceptible to the D pathotype than to the ND one. Nineteen of the 28 cultivars were susceptible or extremely susceptible to both pathotypes of *V. dahliae*. This group includes the most important Turkish commercial cultivars, such as Aksel, BA-151, BA-308, BA-525, BA-Gold, M-503, Maraş 92, Nazilli 84 S, ST-453, ST-468 and ST-488. The second group was characterized by cultivars showing notable differences of resistance depending on the pathotype used (Table 1). Erşan, Flaş, Flora, SG-125 and Şahin 2000 were extremely susceptible or susceptible to the D, but moderately susceptible to the ND pathotype. Third group, BA-119 and Tex were moderately susceptible to the D pathotype of *V. dahliae* and susceptible to the ND one. Last group, ST-373 was moderately susceptible to the both pathotypes and Carmen was susceptible to the D pathotype of *V. dahliae* but not to the ND pathotype.

Analysis of variance for traits associated with resistance to Verticillium wilt of cotton showed significant differences exist among cotton cultivars and *V. dahliae* pathotypes. All plant growth parameters also had significant cultivar x pathotype interaction (Table 2). No significant replication effect was detected. Plant growth parameters were significantly correlated with one another. Leaf–stem ratio, leaf weight and shoot weight showed the highest correlation coefficients with wilt severity caused by both pathotypes (Table 3) but, leaf–stem ratio had the highest correlation and could be considered the best indicator of resistance. This should be used in preliminary tests because it allows rapid identification of the best cultivars. In the analysis of *V. dahliae* pathotypes over cotton cultivars for traits measured, the D pathotype was significantly different from the ND one in terms of disease symptoms and damage to the plants. All traits showed significant differences between pathotypes (Table 4). The LSD tests comparing mean values of cultivars inoculated with D and ND *V. dahliae* pathotypes (Table 5) showed that ST-373, Carmen, Erşan and Şahin 2000 had the highest mean values for each individual trait, while average mean value for Çukurova 1518 (reference control) was significantly lower than the other cultivars.

4. Discussion

Our method proved to be adequate for testing cultivar resistance to Verticillium wilt. The disease reaction showed by the reference cultivars, Çukurova 1518 and Deltapine 15-21, were effectively differentiated in our inoculations by the mean values of AUDPC and PDP, and consistent with those observed in infested field (Bugbee and Presley, 1967; Korolev et al., 2001). Positive isolations of the fungus from affected plants during experiments demonstrated that plants were consistently infected, irrespective of the cultivar, pathotype and resistance level (Garber and Houston, 1967).

Almost all the evaluated cultivars have been catalogued as susceptible or extremely susceptible to both pathogenic variants of *V. dahliae*, including the most important Turkish cultivars (Table 1). Moreover, all the cultivars were more susceptible and showed a higher frequency of positive isolations of the pathogen from affected plant tissues when they were inoculated with the D rather than with the ND pathotype. These results agree with studies of Bejarano-Alcázar et al. (1996), Schnathorst et al. (1975) and Schnathorst and Mathre (1966).

We have also demonstrated that BA-119, BA-525, Candia, Delta Opal, DP-419, Julia and ST-468, cultivars widely used nowadays, show the same susceptibility as Deltapine 15-21 (Table 1). Also, BA-Gold, Flaş and ST-488 were similarly susceptibility as Maraş 92 and Sayar 314 to both pathotypes (Table 1). Carmen was susceptible to the D, but resistant to the ND pathotype (Table 1). This differential reaction could be used to test Carmen in soil infested with low inoculum densities of isolates of the ND pathotypes of *V. dahliae*. ST-373 was moderately susceptible to the both pathotypes and this makes it promising for use in infested soil. This last cultivar showed only slight chlorosis or slight defoliation when inoculated with the ND and the D pathotype, which began to diminish from 10 d after inoculating with either pathotype, reaching medium final values of severity of symptoms.

Using a set of six growth parameters the present study has highlighted the best indicator of resistance to *V. dahliae*. Our results that showed that leaf–stem ratio and leaf weight were useful to quantify resistance for genetic studies, e.g. developing genetic mapping populations in cotton breeding programmes. To our knowledge, no data are available in the literature, with the exception of the work reported by Bölek et al. (2005), who in contrast, stated that the number of healthy leaves and shoot weight were found to be the best indicators of resistance.

In conclusion, the present study is the first to demonstrate that the most commonly cultivated cultivars in Turkey are highly susceptible to both the D and ND pathotypes of *V. dahliae* under our experimental inoculation conditions. The best resistance sources were Carmen, ST-373 and Tex. Consequently, there is a need to

Table 3
Pearson correlation coefficients between mean disease severity of *Verticillium dahliae* pathotypes and plant growth parameters.

	% decrease in					
	Shoot weight	Leaf weight	Stem weight	Leaf to stem ratio	Plant height	Number of nodes
Disease severity	0.51*	0.60**	0.11	0.66**	0.07	0.20
% decrease in						
Shoot weight		0.96**	0.73**	0.70**	0.65**	0.71**
Leaf weight			0.54*	0.83**	0.47*	0.58**
Stem weight				0.08	0.92**	0.83**
Leaf to stem ratio					0.00	0.23
Plant height						0.85**

Significance levels: *$p < 0.01$, **$p < 0.001$.

Table 4
Mean values of two *Verticillium dahliae* pathotypes over thirty cotton cultivars for traits associated with resistance to the pathogen.[a]

Pathotypes	N	Plant height (cm)	Number of nodes	Leaf weight (g)	Stem weight (g)	Leaf–stem ratio	Shoot weight (g)	Verticillium wilt index
Defoliating (Mn/8)	300	15.66 b	5.93 b	1.53 b	1.74 b	0.79 b	3.28 b	3.17 a
Nondefoliating (l/22)	300	16.80 a	6.40 a	2.59 a	2.04 a	1.29 a	4.63 a	2.91 b
Mean		16.23	6.17	2.06	1.89	1.04	3.95	3.04
CV%		14.45	11.08	75.02	28.21	70.01	45.27	11.58

[a] Mean values with the same letter within a column are not significantly different at the 0.05 probability level by LSD.

Table 5
Mean values of thirty cotton cultivars following inoculation with two pathotypes of *Verticillium dahliae* isolates for traits associated with resistance to Verticillium wilt.[a]

Cultivar	N	Verticillium wilt index	Shoot weight (g)	Leaf weight (g)	Stem weight (g)	Leaf–stem ratio	Plant height (cm)	Number of nodes
Aksel	20	3.38^{bc}	2.44^{jklm}	0.87^{jkl}	1.57^{ijkl}	0.51^{hi}	14.90^{k}	6.00^{ghij}
BA-119	20	3.00^{fghij}	3.32^{ghijkl}	2.11^{efgh}	1.20^{m}	1.59^{abcd}	12.62^{l}	5.75^{hijk}
BA-151	20	3.36^{bcd}	2.97^{hijklm}	1.19^{hijkl}	1.77^{hij}	0.73^{gh}	16.25^{ghijk}	5.95^{ghij}
BA-308	20	3.07^{fghi}	4.38^{defg}	2.49^{def}	1.89^{ghi}	1.28^{cde}	16.65^{fghi}	6.45^{cdef}
BA-525	20	2.99^{ghij}	4.94^{de}	2.29^{def}	2.65^{bc}	0.88^{efgh}	18.37^{bcde}	7.00^{b}
BA-Gold	20	3.22^{bcdef}	2.53^{jklm}	0.86^{jkl}	1.66^{hijk}	0.48^{hi}	14.98^{k}	5.72^{hijkl}
Candia	20	3.00^{fghij}	2.91^{hijklm}	1.62^{efghijk}	1.28^{lm}	1.28^{cde}	15.50^{ijk}	5.31^{lm}
Carmen	20	2.56^{lm}	6.96^{b}	4.44^{b}	2.51^{bcd}	1.70^{abc}	17.17^{efgh}	6.55^{cde}
Celia	20	3.44^{b}	4.54^{def}	2.02^{efgh}	2.51^{bcd}	0.93^{efgh}	18.75^{bcd}	7.60^{a}
Çukurova 1518	20	3.80^{a}	2.15^{lm}	0.47^{l}	1.67^{hijk}	0.26^{i}	16.56^{fghi}	5.39^{klm}
Delta Diamond 493	20	3.14^{defgh}	4.71^{de}	2.57^{de}	2.14^{efg}	1.17^{defg}	15.52^{ijk}	6.60^{bcd}
Delta Opal	20	3.00^{fghij}	5.53^{cd}	3.22^{cd}	2.30^{def}	1.42^{bcd}	17.32^{defg}	7.85^{a}
Deltapine 15-21	20	2.90^{ijk}	3.34^{ghijk}	1.63^{efghijk}	1.70^{hijk}	0.93^{efgh}	18.82^{abc}	6.05^{fghi}
DP-388	20	3.07^{fghi}	5.34^{cd}	2.23^{defg}	3.11^{a}	0.76^{fgh}	19.47^{ab}	6.60^{bcd}
DP-419	20	3.00^{fghij}	3.51^{fghij}	2.08^{efgh}	1.42^{klm}	1.41^{bcd}	14.90^{k}	5.92^{ghij}
Erşan 92	20	2.45^{m}	6.24^{bc}	3.82^{bc}	2.41^{cde}	1.58^{abcd}	15.42^{ijk}	5.90^{ghij}
Flaş	20	3.22^{bcdef}	2.44^{jklm}	1.17^{hijkl}	1.27^{lm}	0.76^{fgh}	15.72^{hijk}	6.00^{ghij}
Flora	20	2.92^{hijk}	2.66^{ijklm}	1.53^{fghijk}	1.13^{m}	1.21^{def}	12.17^{l}	6.15^{efgh}
Julia	20	3.02^{fghi}	1.85^{m}	0.62^{kl}	1.23^{m}	0.55^{hi}	12.81^{l}	5.80^{hijk}
M-503	20	2.96^{ghij}	3.03^{hijkl}	1.64^{efghij}	1.39^{klm}	1.19^{defg}	16.47^{fghij}	5.60^{jklm}
Maraş 92	20	3.31^{bcde}	2.71^{ijklm}	1.26^{ghijkl}	1.44^{jklm}	0.81^{fgh}	15.07^{jk}	5.28^{m}
Nazilli 84-S	20	2.91^{hijk}	2.92^{hijklm}	1.27^{ghijkl}	1.65^{hijk}	0.69^{hi}	17.47^{cdefg}	6.46^{cdef}
Sayar	20	3.09^{efghi}	2.62^{jklm}	1.22^{ghijkl}	1.40^{klm}	0.85^{efgh}	16.01^{ghijk}	5.63^{ijklm}
SG-125	20	3.35^{bcd}	3.81^{efghi}	1.84^{efghij}	1.97^{fgh}	0.66^{hi}	16.67^{fghi}	6.00^{ghij}
ST-373	20	2.71^{kl}	8.38^{a}	5.65^{a}	2.72^{bc}	2.02^{a}	20.22^{a}	6.75^{bc}
ST-453	20	3.04^{fghi}	2.17^{klm}	0.95^{ijkl}	1.21^{m}	0.77^{fgh}	12.40^{l}	5.42^{klm}
ST-468	20	3.00^{fghij}	4.55^{def}	1.94^{efghi}	2.61^{bcd}	0.88^{efgh}	17.77^{cdef}	6.30^{defg}
ST-488	20	3.19^{cdefg}	4.63^{def}	1.80^{efghij}	2.82^{ab}	0.64^{hi}	19.67^{ab}	6.75^{bc}
Şahin 2000	20	2.78^{jkl}	7.08^{b}	4.37^{b}	2.71^{bc}	1.53^{bcd}	17.75^{cdef}	6.70^{bcd}
Teks	20	2.45^{m}	3.95^{efgh}	2.56^{de}	1.38^{klm}	1.75^{ab}	13.40^{l}	5.60^{jklm}
Mean		3.04	3.95	2.06	1.89	1.04	16.23	6.17
CV%		12.03	47.96	79.09	28.59	71.30	14.56	11.17

[a] Mean values with the same letter within a column are not significantly different at the 0.05 probability level by LSD.

pursue the search for resistance sources in additional cotton material and closely related species.

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